electrons was reported by Haxel *et al.* (1951) where the electrons trapped in lattice defects created by mechanical abrasion, were subsequently released as exo-electrons by heat treatment. Seeger (1955) also detected the emission of exo-electrons in cases where the crystal defects were created by chemical oxidation process and the after-emission was provoked by means of electron bombardment of energy of about 1000 ev. It is interesting to note that in the present study the curve shown in Fig. 1 closely resembles the time variation curve for exo-electrons obtained by Haxel *et al*, (1951).

REFERENCES

Haxel, O., Houtermans, F. G. and Seeger, K., 1851, *Zeit. f. Phys.* **130**, 122.
Seeger, K., 1955, *Naturwiss*, **42**, 66.

15

CERTAIN THERMISTOR CHARACTERISTICS OF SINGLE CRYSTALS OF TUNGATENITE (WS_2)

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In order to further investigate the self heated thermistor property of naturally occurring tungstenite (WS_2) crystals (already reported, Guha Thakurta, 1967), its steady state current-voltage characteristics have been studied at different temperatures and pressures and for currents along both the crystallographic directions. Further, investigation has also been made under transient conditions wherein the rise of temperature with time is recorded after the sample is suddenly introduced in a high temperature enclosure. Results of these observations are graphically represented in figures 1, 2 and 3. It is to be noted here that as the behaviours are similar in both the principal directions, results of measurements in one direction only are given in the diagrams.

It is observed from figures 1 and 2, that the voltage always attains a maximum value say V_m, for a particular value of current and at a particular ambient temperature and pressure and then begins to decrease with further increase of current. This V_m together with I_m, W_m, and T_m the corresponding current, wattage absorbed by the sample and the temperature of the sample respectively are evidently important quantities in deciding the peculiarities of a particular thermistor, have been obtained from a study of fig. 1, and the values for the particular sample

corresponding to figure 1 when the ambient temperature is about 303°K and pressure 9.5×10^{-2}mm. of Hg are shown in table I. These quantities calculated theoretically following standard relation (Becker *et al* 1946, 1947) and from a knowledge of its activation energy and dissipation factor (both obtained separately) are also shown in the same table.

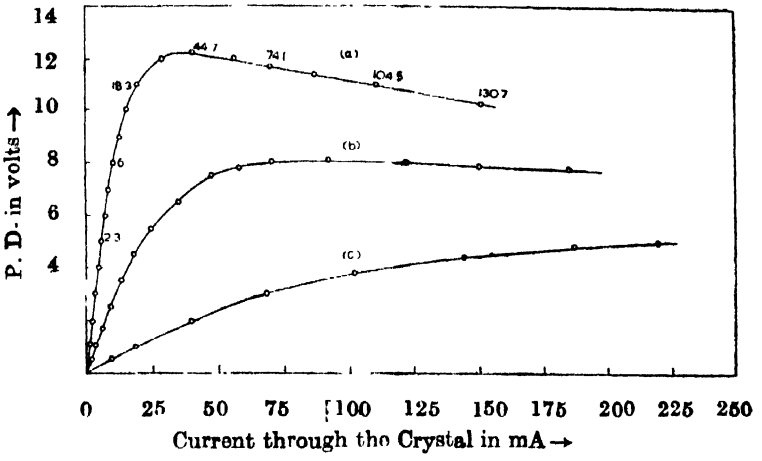

Fig. 1 Steady state current—voltage characteristics of WS_2 for currents along the C-axis at a superincumbent air pressure 9.5×10^{-2} mm of Hg., and at different ambient temperatures.

(*a*) Ambient temperature = 303°K.
Figures on the curve indicate the rise of temperature of the specimen in °K above the ambient.

(*b*) Ambient temperature = 376°K.

(*c*) Ambient temperature = 500°K.

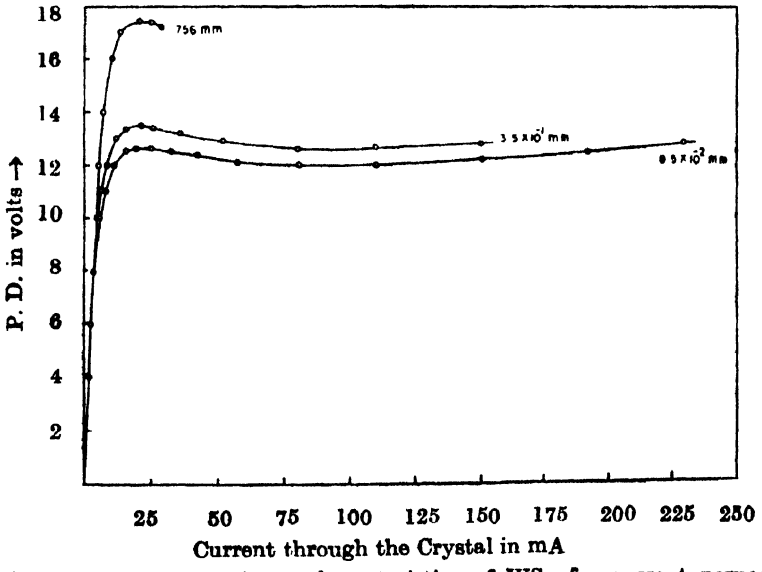

Fig. 2. Steady state current—voltage characteristics of WS_2 for current perpendicular to C-axis at an ambient temperature 333°K, and at different air pressures.

TABLE I

Activation energy = 5220°K

Resistance of the specimen at the ambient temperature 303°K and pressure 9.5×10^{-2}mm. of Hg. = 9.09×10^{2} ohms

The dissipation constant is 1.104×10^{-2} watt/°K

	Experimental	Theoretical
T_m (temperature corresponding to peak)	347°.7K	348°.3K
W_m (watts' ,, ,,)	49.53×10^{-2} watt	49.97×10^{-2} watts
Rm(resistance ,, ,,)	3.00×10^{2} ohms	3.00×10^{2} ohms
V_m (voltage ,, ,,)	12.20 volts	12.25 volts
I_m (current ,, ,,)	40.60 mA	40.80 mA

The steady state mentioned above is attained only after the rise in temperature of the crystal due to the passage of current through it is balanced by the dissipation of heat of the crystal to the surroundings. The dissipation constant G is related to current and voltage by the equation $G(T-T_0) = V\times I$, where T is the temperature of the crystal when a current I at a voltage V passes through the crystal and T_0 is the temperature of the surroundings. Thus from a study of watt against temperature curve, the dissipation constant G can be found out. It is needless to mention here that the dissipation constant is dependent on the superincumbent air pressure as is evident from fig. 2, where current—cvoltage characteristics are found to be different at different pressures (evidently due to differences in the values of G (Table II)) and this fact allows one to use the thermistor as a pressure measuring device.

TABLE II

Dependence of dissipation constant G on the surrounding air pressure (calculated from fig. 2).

Surrounding air pressure in mm. of Hg.	G in watt/°K	G per unit area
9.5×10^{-2}	2.137×10^{-3}	1.583 mw/°K
3.5×10^{-1}	2.370×10^{-3}	1.756 mw/°K
756	4.083×10^{-3}	3.025 mw/°K

In the transient condition, the rise of temperature is given by

$$T-T_0 = A_e^{t/\tau}$$

where T is the temperature of the crystal in degrees Kelvin at time t, τ is a constant known as time constant and A is also a constant. Again $\tau = C/G$ when C is the thermal capacity and G, the dissipation constant. Thus from a study of the time-temperature curve and a knowledge of G, one can find out the value of C of the specimen at a temperature T°K. It is, however, to be pointed out here that this relation does not hold at higher temperatures when the radiative losses become more pronounced and the thermal capacity also changes much with temperature. One such calculation with values obtained from the linear portion of the time-temperature curve (fig. 3) yields a value for C of WS_2, within the temperature range

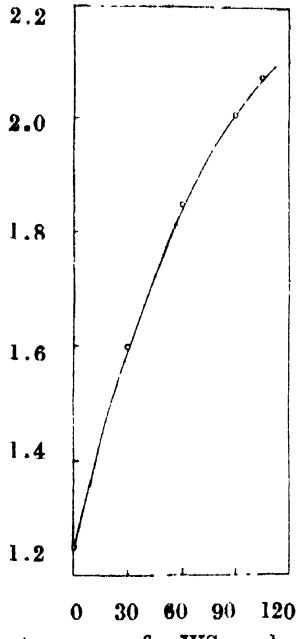

Fig. 3. Time-temperature curve for WS_2 under transient condition.

303°K—333°K, as 0.57 joule/°K per gm. which compares well with 0.4 joule/°K per gm., the corresponding value of the specific heat of MoS_2, the isomorphous crystal, obtained by direct measurements (there being no reported value of specific heat of WS_2 available for comparison).

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REFERENCES

Guha Thakurta, S. R., 1967, *Indian J. Phys.* **41**, 99.

Becker, J. A.; Green, C. B. and Pearson, G. L., 1946, *Transaction of the American Institure of Electrical Engineers* **65**, 711.

Becker, J. A.; Green C. B. and Pearson, G. L., 1947, *Bell system Technical Journal*, **26**, 170.